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INVESTIGATION, PRESERVATION AND RESTORATION PROCESSES OF AN ANCIENT EGYPTIAN WOODEN OFFERING TABLE

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Abstract

The wooden offering table studied here dates back to the Middle Kingdom (2040 – 1782 B.C), and consists of wood and yellow pigment. This study aims to use analytical techniques to identify the components of the table and to understand its deterioration aspects. Visual assessment, isolation and identification of fungi, ultraviolet spectroscopy scanning, optical microscopy, scanning electron microscopy, X-ray fluorescence spectroscopy, X-ray diffraction, and Fourier transform infrared spectroscopy were used to assess wood deterioration and degradation, to identify wood species, pigments, and previous preservation and restoration materials. The results revealed that the wood species is cypress (Cupressus sempervirens L.), used for the body of the offering table, while the dowels are made of hardwood; the pigment used on the table is yellow ochre and the previous preservation and restoration materials are a mixture of beeswax and rosin. The offering table is severely damaged by old fungi infection, Aspergillus sp., Cladosporium sp. being were the most dominant fungi found on the offering table. The offering table was previously restored and reassembled by using new dowels made of softwood and extensively amount of a mixture of beeswax and rosin, especially in the four connecting points between the four legs and the four horizontal rails.

Keywords: *Preservation; Restoration; Offering table; Wood; Fungal degradation and deterioration; SEM; FTIR; OM.*

Introduction

The offering table, object of this paper, represents one of the most important elements of the Egyptian private tomb throughout the Pharaonic and Greco-roman periods. It was usually placed in an accessible location such as the chapel, so that offerings could be brought to it by the funerary priests or relatives of the deceased [1].

The studied offering table (GEM No 1432) (Fig. 1), dates back to the middle kingdom period, found in Dahshur necropolis located in the desert on the west bank of the Nile - Giza. The rectangle top of this four legged table is made of two wooden pieces with U-shape wooden rails, held together by dowels. Each leg is carefully shaped from one piece of wood, supported in the middle by four wooden rails, which connected to each leg by wooden tongue carved in the same rail while mortises are carved in the legs. The legs were connected to the top by wooden dowels, while the whole table is colored by yellow pigment. The table is slightly sliding from back to front.

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The offering table dimensions are about 32cm in height (max), 35.2cm in width and 23.2cm in depth (Fig. 2).

Fig. 1. General View of the offering table (upside-down)

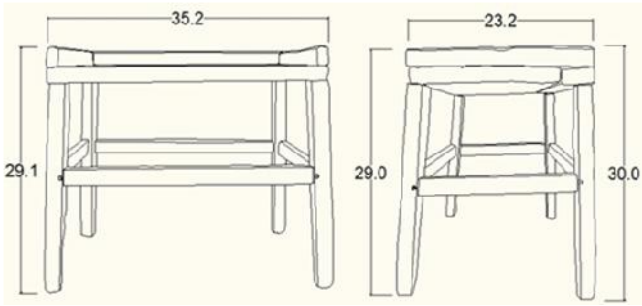

Fig. 2. 2D drawing of the front and left sides of the offering table, showing its dimensions

Materials and methods

Scientific analytical techniques, such as optical microscopy (OM), environmental scanning electron microscopy (ESEM), X-ray fluorescence spectroscopy (XRF), X-ray diffraction (XRD), Fourier transform infrared (FTIR) spectroscopy and microbiological investigation were applied to elucidate the nature of the original and added materials, to explain the deterioration processes, as well as to establish the state of conservation of the offering table.

Visual assessment

Visual assessment, by the critical eye of the team work, was applied to determine the aspects of deterioration found on the offering table. This method is very effective because the causes and mechanism of deterioration may be easily identified. The critical eye of conservator can also determine the most effectiveness techniques of analysis, which should be applied for identifying the condition of the studied offering table [2, 3].

Documentation of the Deterioration aspects by 2D program & photography

Aspects of deterioration and previous preservation and restoration interventions were documented by using a high-resolution digital camera image (Sony Cyber-shot DSC-H300, 20.1mp, 35×Optical zoom) used to create realistic photographic documentation.

Computer Aiding Drawing (CAD) program was applied to illustrate the broken wooden joints by creating a map of the offering table which illustrates the techniques of wooden joints.

Optical Microscopy (OM)

A stereo microscopy (Zeiss Stero DV 20, equipped with Axio Cam MRC5) was used to study the stratigraphic structure of the painted offering table, and wood surface morphology attacked by microorganisms [4].

A thin section of wood samples, taken from the offering table, were used for species identification., The three principal anatomical directions of wood, transverse section (TS), longitudinal radial section (LRS), and tangential section (LS) were examined. Thin sections (30-50μm) were mounted on slide glasses by a mixture of Arabic gum, trichloroacetaldehyde monohydrate, glycerin (glycerol) and pure water for one day. A light microscope Optika B-383PL equipped with digital camera 4083-B9, was used for identification of wood species [5, 6].

Environmental Scanning Electron Microscopy (ESEM)

A Quanta 3D 200i scanning electron microscope made by FEI was used for assessment of deterioration and changes in wood cells [7]. The accelerating voltage was between 10-15 kV in the field of magnification orders of 400 to 800X. The investigation was carried out in both methods: the large filtered detector mode (LFD) and the backscattered electrons mode (BSE).

In order to assess the damage in wood cells a tow specimens of the old decayed wood and un-decayed wood of the same species have been investigated.

X-Ray Fluorescence (XRF)

In order to identify the yellow pigment found on the offering table X-Ray fluorescence measurements were carried out with portable system, thermo scientific Niton XL3t analyzer including X-ray tube with Ag anode, 50kV and 0-200µA max, spot diameter 3mm and duration of exposure 60 second.

X-ray Diffraction (XRD)

The yellow pigment on the offering table was analyzed by X-ray diffraction using X-ray Diffractometer System PW3040–AnalyticalEquipment–PANalyticalpro model, Cu-target tube and Ni filter at 40kV and 30MA using. X'PertHighscore software was used.

Fourier Transformed Infrared Spectroscopy (FTIR)

Fourier transform infrared spectroscopy was done using FTIR spectrometer (VERTEX 70, Bruker) equipped with An attenuated total reflection (ATR) in the 400–4000cm^{-1}, range with resolution of 8cm^{-1}, was used to identify previous preservation and restoration materials. For the assessment of the deterioration of wood attacked by microorganisms, FTIR spectra of decayed sample and un-decayed control sample were measured by using Shimadzu FTIR spectrometer, the KBr pellet technique. Spectra were recorded using IRPrestige-21-FTIR spectrometer and the IRsolution software in the transmission mode 400– 4000cm^{-1}, range with resolution of 4cm^{-1} and 50 scans were averaged [8, 9].

Isolation and identification of fungi

Sterile swabs were used to wipe the surface of the offering table to isolate the fungi, especially in the old infection areas. Isolation was made directly in the laboratory after wiping process. The fungi were isolated by wiping the swabs on culture medium of potato-dextrose agar (PDA) then incubated at 28°C for 7 days [10, 11], cellulose medium at 28°C for 21 days [12], and lignocellulose medium at 28°C for 21 days [13, 14] were used for identification of isolated fungi. Also, fungi colonies were identified according to previous reported protocols [15, 16].

Detecting fungi by auto fluorescence spectroscopic technique

Auto fluorescence spectroscopic technique is a simple and quick procedure that can be exploited on fungal detection.

In the most of cases, excitation can be obtained by using near ultra violet (UV) light, with wavelength (λ) going from 320 to 400nm. After the absorption of UV light by fluorochrome, radiation of longer wavelength (visible light) is emitted [17].

The Dino-Lite digital microscope has been used for detecting fungal infection using ultra violet (UV) light. Dino_capture 2 software was used for capturing digital images.

Results and discussion

Visual assessment

Previous preservation and restoration materials are clearly visible in the offering table (Fig. 3), together with new dowels, especially in tow connecting points between legs and wooden horizontal rails at the left side (Fig. 4).Wood exhibits different conservation conditions from robust to desiccated and brittle and can be fractured and pulverized between the fingers. There was evidence of severely biological damage, shown as cubic and horizontal cracks, in all the offering table especially in legs and rails (Fig. 5); the two tongues which connect left side legs with front and back rails are broken; the left back leg is separated due to break at the new dowels used in connecting the leg to top table and rails (Figs. 6 and 7). Besides, physical deterioration, such as cracks, abrasion and loss, has been observed.

Documentation of the deterioration aspects by 2D program

The broken points of the offering table were recorded in detail and each break was carefully recorded using 2D program. This technique produced clear documentation of the offering table breaking conditions as shown in figure 8 which illustrates that all broken points were located in left side.

Techniques of collecting table components (panels, rails and legs) are carefully documented as shown by figure 9 which indicates that the ancient Egyptians used a wooden dowels for collecting the upper U-frame to top panels and to collect this group to the legs, while in collecting legs to rails another wooden joint, mortise and tenon joint secured by dowels, has been used [18].

The following aspects of deterioration were noticed on the offering table: the surface was extensively embedded with dust, as well as cracks, missing painted layer in many places, and color alteration. The previous preservation and restoration material (resinous material) is embedded with yellow pigment and wood in some areas.

Fig. 3. A thick bulk of previous preservation and restoration material, at the connecting point between the front rail and front

Fig. 4. A previous new dowel used in assembly of offering table.

Fig. 5. Horizontal cracks and cubic breaks due to Fungal

Fig. 6. Broken tongues in front and back rails.

Fig. 7. Left front leg separated from the offering table and remains of broken tongue in mortise as shown by arrow.

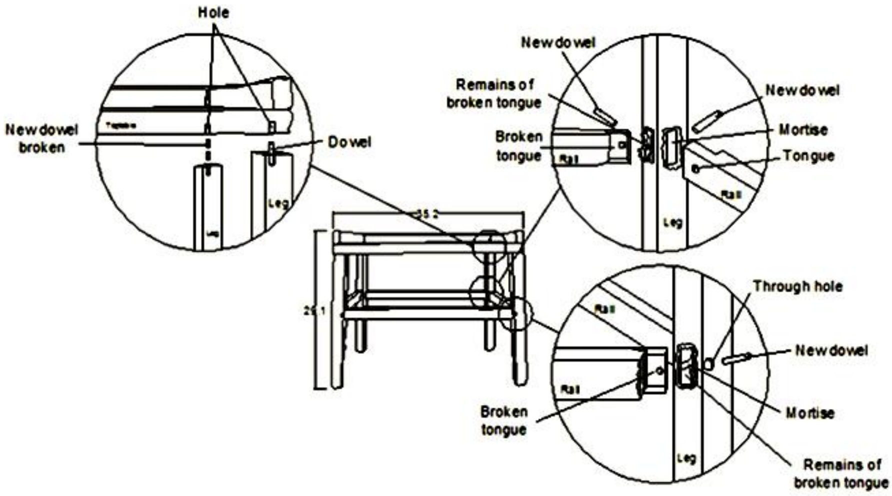

Fig. 8. 2D drawing illustrates the broken connecting points in offering table

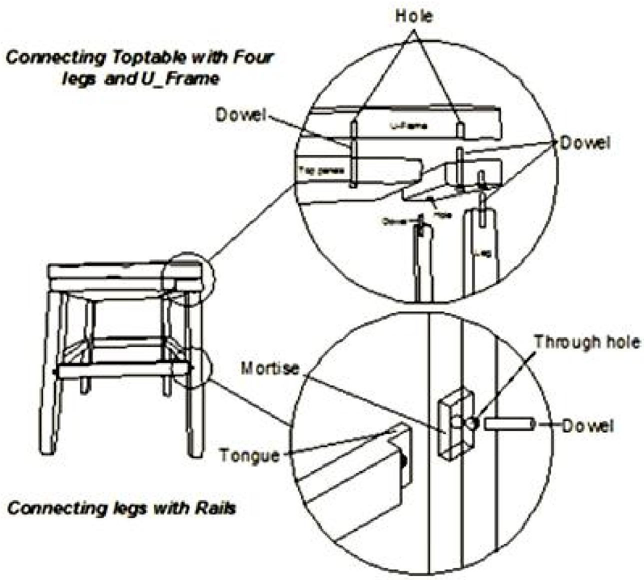

Fig. 9. 2D drawing illustrates techniques of collecting offering table components.

Optical microscopy

Technique of decoration

Wood substrates in ancient Egyptian objects are often covered with several kinds of ground layers; mud, gypsum and whiting (chalk). This ground layer either applied as a single structured layer or layers of coarse and fine layer followed by painting layer [19, 20].

But sometimes pigments are applied directly to wood surface. This is the case of the offering table. In fact, investigation of the stratigraphic sequence by stereo microscope showed that the yellow pigment is applied directly to wood surface (Fig. 10).

Fig. 10. Longitudinal section shows yellow pigment applied directly to wooden substrate. Stereomicroscope, magnification 400X.

Examination of the fungal degradation

The morphological degradation patterns can be used to determine the type of decay and the casual agent, and the information obtained from previous studies of microbial degradation have provided a useful classification system for fungal and bacterial degradation of wood [21, 22].

Fungi that cause wood decay have been classified into broad categories of white, brown, and soft rot based on the color and texture of the residual wood after decay [23, 24].

Brown-rot fungi rapidly depolymerize cellulose during incipient stages of wood colonization. Considerable losses in wood strength occur very early in the decay process, often before decay characteristics are visually evident, and the residual wood is brown and often cracks into cubical pieces when dry [25].

Morphological investigation by stereo microscope showed that the wood surface of offering table is cracked into cubic (Fig. 11), that indicates the essential fungi infection may be occurred by brown rot species.

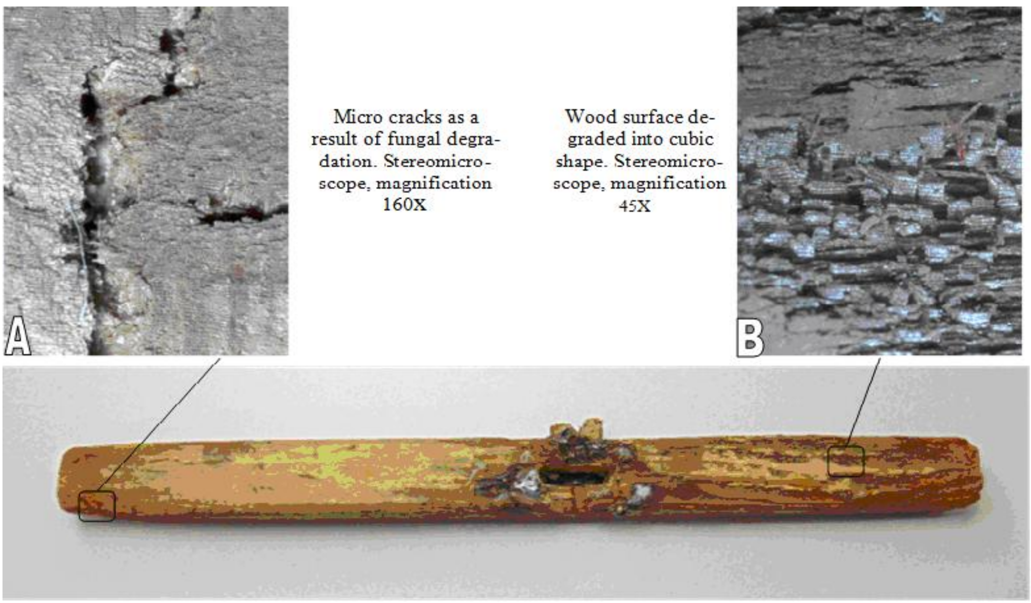

Fig. 11. Examination of wood surface degraded by fungi under stereomicroscope magnification 160X and 45X.

Identification of Wood

Optical microscopy, used for identifying wood species, indicated that the panels of the offering table is made of cypress(*Cupressus Sempervirens* L.). Cypress is not an Egyptian tree and probably was not introduced into the country until modern times; it grows, however, plentifully in both southern Europe and western Asia [26, 27].

The diagnostic characteristics used to identify cypress wood were softwood (trachieds present, vessel absent), axial parenchyma diffuse in tangential band (Cross), rays mostly uniserate, 3-20 cells high, (tangential) rays are composed of parenchyma cells with smooth end walls, cross-field pits in rays, 2-4 per field, cupressoid (radial), resin duct absent (cross and tangential) (Fig. 12) [28].

Wooden dowels used for collecting table components are made of hardwood, vessels present, as showed by USB microscope imaging (Fig. 13).

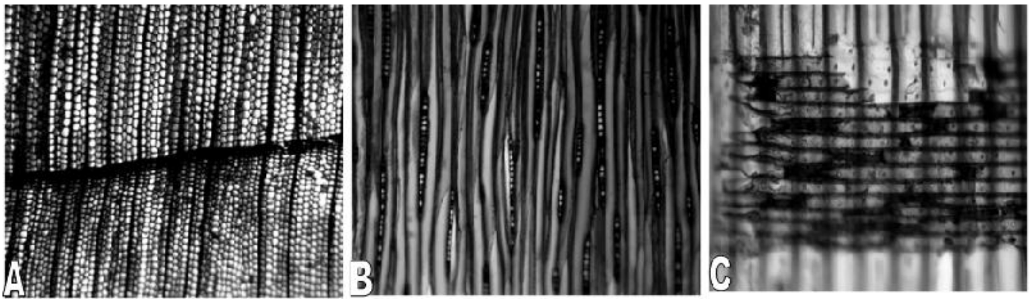

Fig. 12. Identification of wood: (A) Transverse section (TS) showed growth ring, composed of equilateral bronchioli, vessels and resin ducts are absent, magnification (40X). (B) Tangential section (LS) showed rays cells mostly uniserate, 3-20 cells high, magnification (100X). (C) Radial section showed rays are composed of parenchyma cells with smooth end walls, cross-field pits in rays, 2-4 per field, cupressoid, magnification (200X).

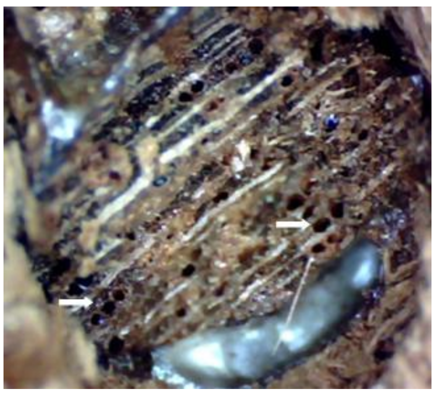

Fig. 13. Image of transverse section of a wooden dowel used in collecting wooden table components indicates vessels present (arrows).

Environmental Scanning Electron Microscopy (ESEM)

Wood consists of an orderly arrangement of cells with walls composed of varying amounts of cellulose, hemicellulose and lignin [29].

A comparative study between SEM micrographs of un-decayed and decayed wood attacked by brown-rot showed that, the degradation of cellulose in woody cell walls leaves a residual network of lignin, cell walls collapse and appears distort, degraded cells showing walls that are porous, disrupted and fragile, the decayed samples exhibiting generalized thinning and erosion of the cell walls leading to breakdown of the wood cells which became easily fragmented (Fig. 14).

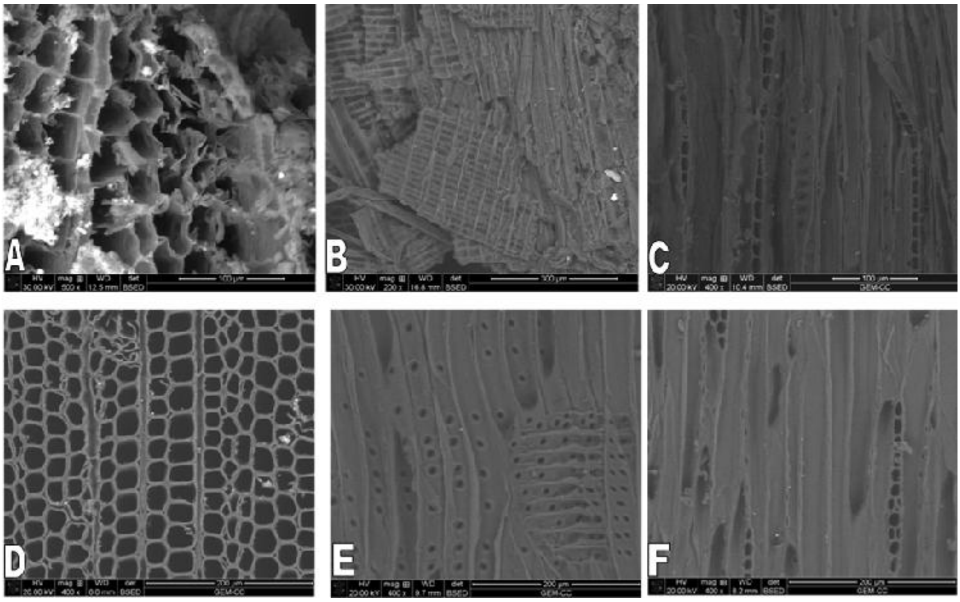

Fig. 14. SEM micrographs of degraded wood (A, B, C) and sound wood (D, E, F): A - Degradation of cellulose in woody cell walls (TS) leaves a residual network of lignin. Cell walls collapse and appear distorted; B - Radial cells (RLS) are broken, disrupted and fragile; C - Micrograph of tangential section showed horizontal micro cracks and separation

X-ray Fluorescence analysis (XRF)

XRF spectroscopy on the yellow color revealed the presence of Fe, as main element, suggesting the use of yellow ochre as pigment (Fig. 15) [30].

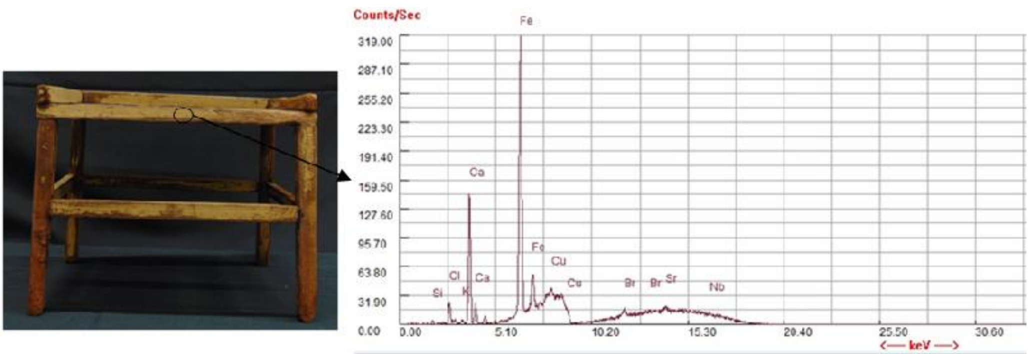

Fig. 15. Characteristic XRF spectrum of yellow color

X-ray diffraction analysis (XRD)

XRD spectrum of the yellow pigment confirmed the presence of yellow ochre, revealing a mixture of quartz, goethite, kaolinite. The compound responsible for yellow color is goethite. Goethite, a naturally occurring mineral, is an iron oxide hydroxide with the formula α-FeOOH., [31, 32].

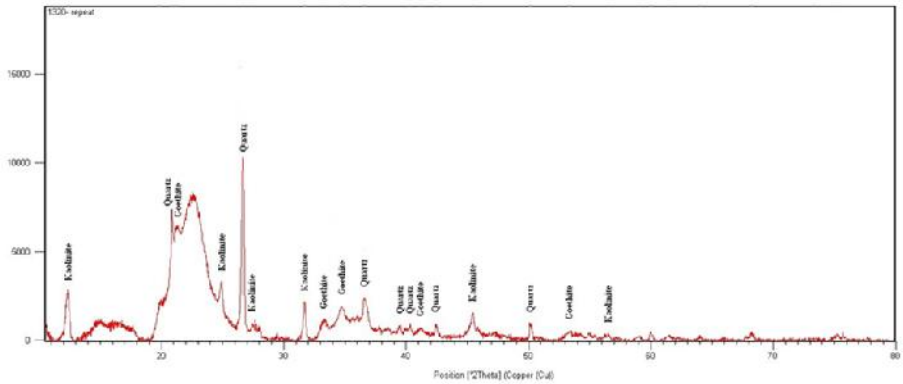

Fig. 16. XRD analysis of yellow pigments

Fourier Transform Infrared Spectroscopy (FTIR)

Identification of previous preservation and restoration materials

Fourier transform infrared spectroscopy analysis indicates that the previous preservation and restoration materials are a mixture of beeswax and rosin, after a comparison with a control sample of pure beeswax and rosin (Fig. 17). Many natural resins are extracted from trees and plants and are based on terpenoid structures [33, 34]. Such resins have been used extensively as preservation and restoration materials because of their attractive properties including adhesion, water insolubility and glassiness [35].

The beeswax has been added to rosin to improve the mechanical and handling properties of the material.

In case of a mixture of wax with terpenoids (resins) the intensity of the bands in the region of absorption of un-ionized carboxylic groups (~ 1710cm^{-1}) rises [36].

The FTIR spectra (Fig. 17) show the characteristic bands of bees wax and rosin mixture: the absorption bands at 2917 and 2849cm^{-1}due to stretching vibrations of C-H groups; 1734 and 1694cm^{-1}associated to stretching vibrations of the ester carbonyls and CO groups of un-ionized carboxylic acids, respectively; the absorption bands at 1471cm^{-1} in old sample and 1472-1464cm^{-1} in standard samples are planar deformation vibration of CH groups; 1300-900cm^{-1}are the C-O stretching bands [37].

Evaluation of wood condition

The FTIR spectra of decayed and un-decayed cypress wood showed structural and chemical changes induced by various degradation mechanisms in decayed sample.

The FTIR spectra of two samples exhibit common features in the 3500-2500cm^{-1} range: a band at 3417cm^{-1}, assigned to the O-H stretching vibration, for the water molecules absorbed in the wood lumen cells, and a prominent band at 2920cm^{-1}, corresponding to the C–H stretching vibration of organic moiety. In the 1800-600cm^{-1} fingerprint area, the un-decayed sample exhibits specific and common bands assigned to cellulose, hemicellulose and lignin moieties, as follows: 1735cm^{-1} assigned to unconjugated C=O in xylan (hemicellulose), 1654cm^{-1} for absorbed O-H and conjugated C-O , 1508cm^{-1} a band specific to aromatic skeletal vibrations (this band depends on the wood species and is assigned to the total content of the lignin components); 1458cm^{-1}, and 1423cm^{-1} for C-H bands in lignin; 1373cm^{-1} of C–H in cellulose and hemicellulose; 1319cm^{-1}, for C–H vibration in cellulose; 1269cm^{-1}, vibrations of the guaiacyl rings and stretching vibrations of the C-O bonds (observed in softwoods); 1157cm^{-1}, for C-O-C vibration in cellulose and hemicellulose; 1053-1029cm^{-1} C–O in cellulose and hemicellulose, and 898cm^{-1} for C–H in cellulose [38-41] (Fig. 18).

Apart from a number of environmental parameters that contribute significantly to the degradation of wood, the rate of degradation may also be affected by the wood properties, e.g.

presence of extractives and kind of wood. For example, it is known that hardwoods degrade at a slow rate than softwoods [42].

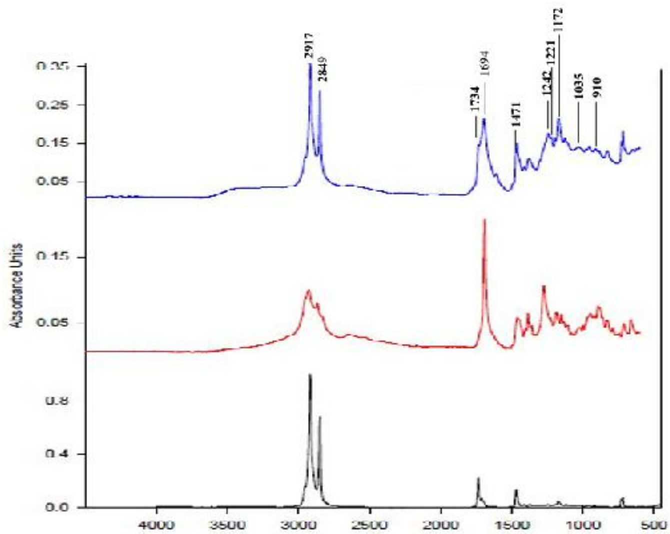

Fig. 17. FTIR spectra of (A) sample from the offering table referred to previous preservation and restoration material, (B) Rosin reference sample, and (C) Beeswax reference sample

The FTIR spectra of decayed sample showed significant changes in chemical structure; the intensities of carbohydrate bands at 1735, 1373, 1319, 1157, 1053, 1029 and 898cm^{-1} are severely decreased due to microbial infection and aging, with those bands at 1373, 1319, 1157 and 898cm^{-1} almost absent, while the band at 1735cm^{-1} shown as a shoulder, is due to residual of xylan, which indicate that the cellulose and hemicellulose is heavily deteriorated, and explain how the wood is very fragile. Intensities of absorption bands resulting from lignin at 1597, 1508, 1458, 1423, 1269cm^{-1}, showed relatively decrease in intensities comparing to carbohydrates bands [38].

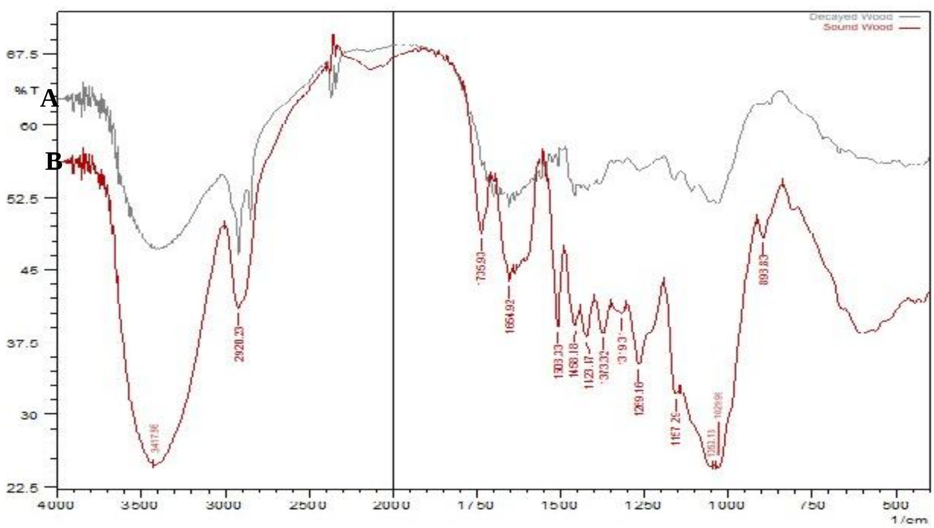

Fig.18. FTIR spectra of (A) decayed, and (B) un-decayed wood.

Isolation and identification of fungi

Wood is an organic material susceptible to numerous biodeterioration processes, which generally cause the loss of aesthetic properties and often the irreversible degradation of important works of art.

The ability of rot fungi to degrade wood varies among fungal species and depends on the chemical properties of wood and on its structural features. Wood decay is initiated by fungal enzymes, acting on the cell wall components of the wood. Although most of the wood-rotting fungi are able to degrade both cellulose and lignin, they exhibit different degradation rates for these substances. The growth characteristics of the microorganisms in wood and the type of degrading system produce different decay patterns. Depending on the type of decay, different physical, chemical and morphological changes occur in wood. According to the macroscopic differences of their substrate utilization, wood rots are classified into three specific decay groups: white rot, brown rot, and soft rot fungi [25, 43, 44].

The results of this study revealed the presence of the following main fungi: *Aspergillus flavus, Aspergillus versicolor, Cladosporium sp.*

The growth of microorganisms on selected media, showed one colony per plate, indicating that the infection is weak.

Detecting fungi by auto fluorescence spectroscopic technique

The data obtained by imaging with UV radiation showed that there are no fluorescence spots of fungi on wood surface (Fig. 19). This result indicates that there is no active fungal infection.

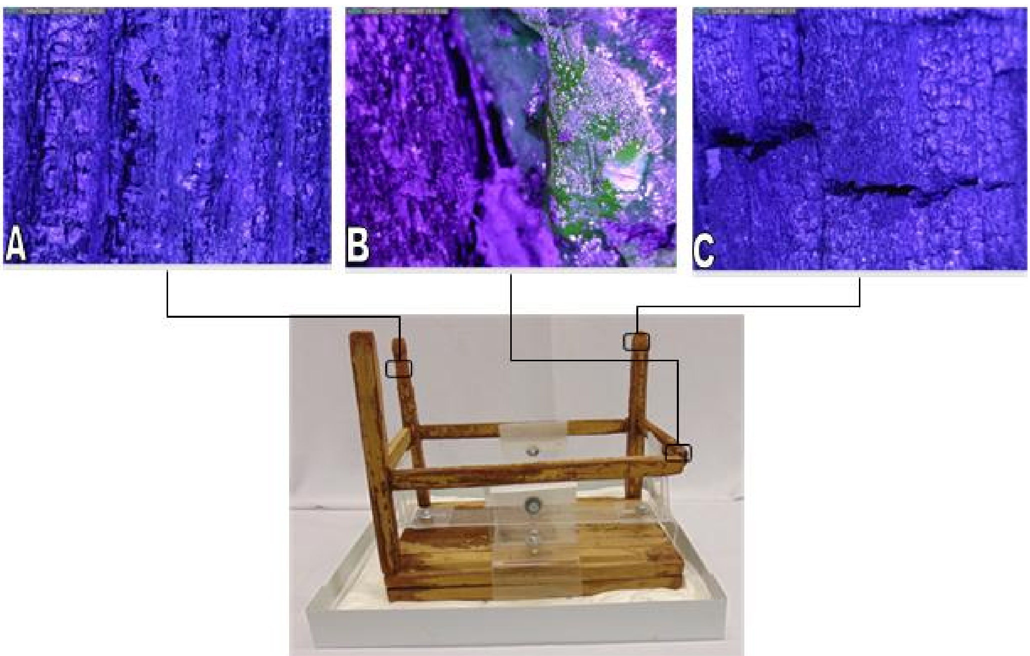

Fig. 19. imaging with UV showing no evidence of active infection by fungi. Right section of image (B) shows residual of previous preservation and restoration material (mixture of rosin and beeswax)

Preservation and restoration Processes

The main purpose of Conservation Science is the preservation and restoration of artifacts in such a condition that future generation may experience them and study their value [45]. In order to support the broken rails and legs a Plexiglas stand had been designed and is ready to adjust for height and depth by screw nails. Several processes were employed as soon as the offering table was transported to wood lab entailed cleaning such as: consolidation of friable pigment layer and wood substrate, removal of previous restorations and loss compensation, reassembly of broken and loose parts.

Surfaces Cleaning

In spite of this offering table was displayed in show cases of the Egyptian museum, layer of fine dust were found over the surface. Loose dust was removed by gentle brushing, whereas mechanical cleaning, proceeded by chemical cleaning, was necessary to remove the remaining dust that still suspended to the surface of the painted layer, Cotton swabs immersed in ethyl alcohol were rolled over the surface to remove remaining dust.

Consolidation of friable paint and degraded wood

Owing to the brittle and fragile condition of the paint and wooden substrate, a consolidant was needed to strengthen both layers and improve the cohesion of surface particles and adhesion to substrate. By evaluating the results of a number of spot tests on small areas of wood, and paint and with reference to work carried out by conservation researchers [46-48], a suitable consolidant was chosen.

Reversibility, alteration in appearance, improvement in the cohesion of surface particles and adhesion to substrate were all considered in the testing of the following materials: Klucel G (hydroxypropyl cellulose), Plexisol P550 (poly butyl methacrylate), Regalrez 1094 (hydrogenated oligomers of styrene (vinyl benzene, ethenylbenzene) and α-methyl styrene (isopropyl benzene or 1-methyl-1-phenyl ethylene).

Solutions of 0.5 and 1%w/v Klucel G in ethyl alcohol, for paint layer, gave least discoloration of paint material and consolidate friable pigment efficiently and with minimum disturbance. Areas requiring treatment of wood substrate, particularly, where loss of the paint had occurred, were dampened with ethyl alcohol applied by pipette. This served a dual function: as a mild fungicidal treatment and as a wetting agent prior to application of the Regalrez 1094 and Klucel G solutions. Use of the ethyl alcohol facilitated absorption of the consolidant. Solutions 5-7%w/v of Regalrez 1094, applied by sable brush, improved the mechanical properties of wood.

Removal of previous restorations

As the FTIR analysis proved that the previous preservation and restoration materials are mixture of beeswax and rosin, a poultice of cotton fibers saturated with toluene covered by foil was helpful in softening these materials, which were then removed or reduced by slicing with mechanical methods, e.g. scalpels, dental tools etc. (Fig. 20). Several solvents were tested to assess the solubility of the mixture of beeswax and rosin; 1,1,1-trichloroethane and toluene were most effective in reducing the layer, but did not remove it entirely. The mechanical action of rolling a cotton wool bud over thin layer of the mixture of beeswax and rosin surface tended to remove it from upper surface, leaving deposits in the trough and wood cells. So, some of the old preservation and restoration material had to be left *in situ* because it had become embedded in the paint surface and wood substrate and could not be removed without damage to original surface.

In order to remove the new broken dowels used in collecting the offering table, toluene was injected around those dowels then removed by loosening with tweezers (Fig. 21).

Reassembly the components of offering table

As the original and new tongues and dowels on the left side of the offering table were broken, new dowels made from beech wood and Paraloid B-72 50% dissolved in acetone were used, besides clamping, for reassembly of the components of offering table. Remains of original broken tongues were reattached in the original mortises.

Before drilling for new dowels that will be used in collecting the offering table components, and in order to support the chosen spot for drilling, a sheet of Japanese tissue paper had been rolled around the rails, then a rectangle piece of balsa wood had been tied over the tissue paper by using non-bleaching weaving cotton tape (Fig. 22A and B).

The purpose of clamping is to apply pressure to the right parts of an assembly to bring parts being adhered into close contact with the correct alignment. A jack tie was used to collect the components of the offering table in correct alignment, and achieving even distribution of pressure on assembly points (Fig. 22E and F).

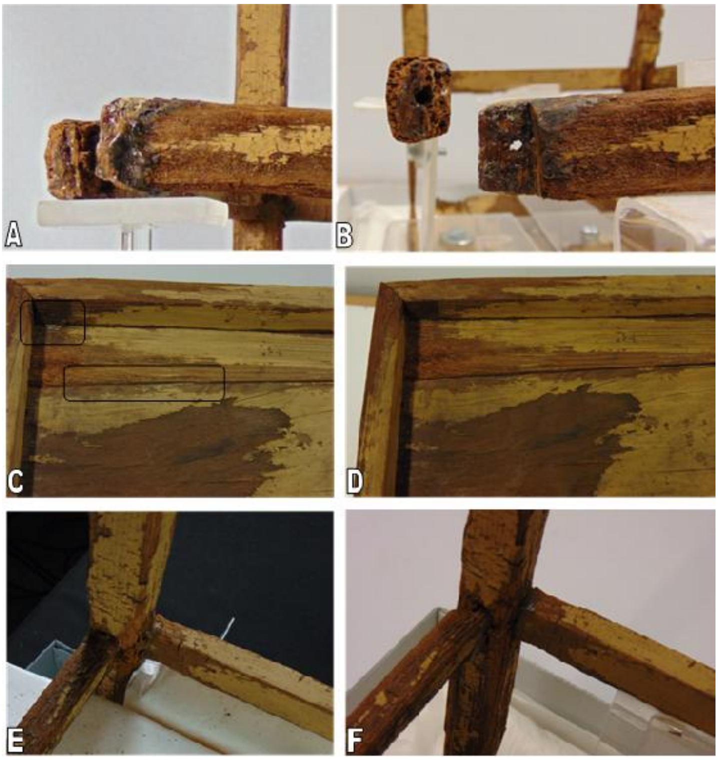

Fig. 20. Reducing and removing the excessive use of previous preservation and restoration materials: (A,C,E) before, and (B,D,F) after removal.

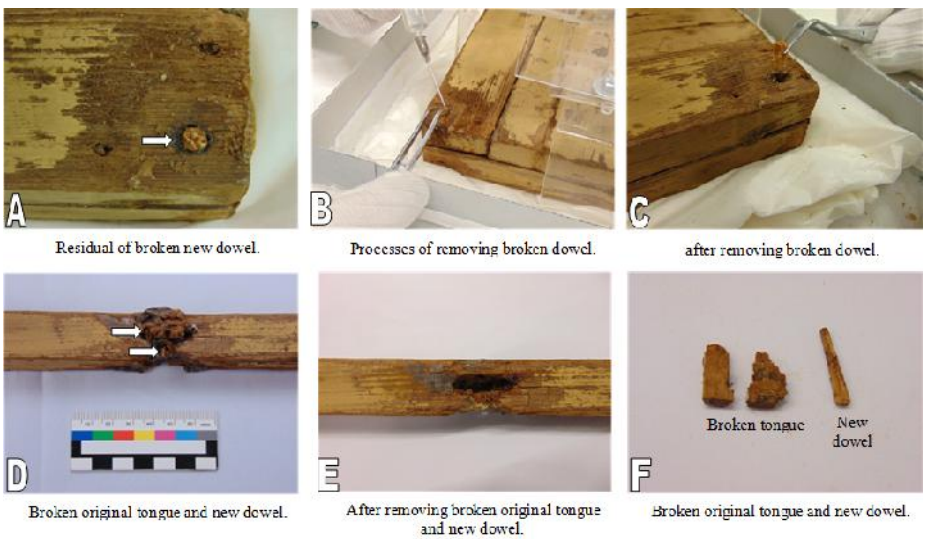

Fig. 21. Processes of removing and dismantling the broken new dowels and original broken tongue.

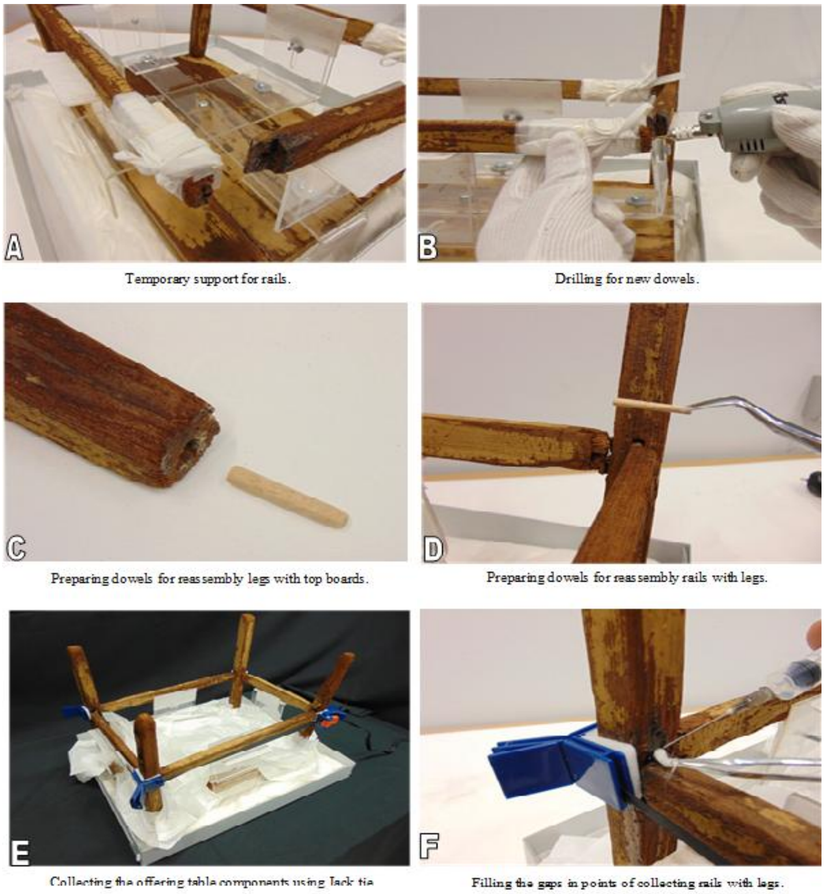

Fig. 22. Processes of reassembly the components of offering table.

Loss Compensation

Based on experimental studies and evaluation on gap fillers applied by preservation and restoration team work [49], and on termites-damaged coffins found in tombs KV63, Valley of the Kings, Luxor [50], a cotton fiber saturated with Paraloid B-72 dissolved in acetone 15% (1gm/15mL) was used for filling gaps in lines of collecting points. Then putty consisting of 15%w/v Paraloid B72 in acetone, glass Microballoon and earth pigments was applied until the outer surface reached the expected level (Fig. 23A and B).

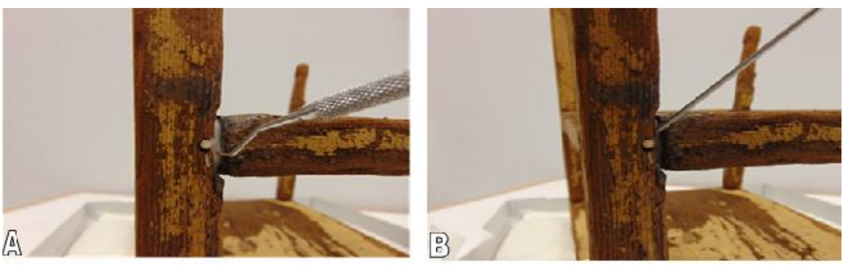

Fig. 23. Processes of Filling gaps: (A) cotton fibers injected by Paraloid B-72 15%.
(B) a mixture of glass micro-balloon with Paraloid B-72 and oxide with suitable color hue

Fig. 24. The offering table before preservation and restoration

Fig. 25. The offering table after preservation and restoration

Conclusions

This study proved that the offering table studied suffers from severely deterioration and degradation phenomena caused by environmental, biological and mechanical factors. Visual assessment and documentation using 2D software showed that the main break occurred in the left side. Wood identification indicates that the ancient Egyptian carpenter used softwood of cypress for making the main elements of the offering table (panels, rails and legs) and assembly them by dowels made from hardwood. The examination of decoration layer, using OM, indicates that the yellow pigment was applied directly to wood surface. SEM micrographs, OM images and FTIR analysis were effective in assessment of wood deterioration and introduce a complete vision of wood condition; isolation of fungi and auto fluorescence spectroscopic technique proved that fungal degradation is a result of previous infection.

The offering table was confirmed to be in bad condition, a Plexiglas stand was efficient to hold broken elements in proper level during preservation and restoration processes. Regalrez 1094 was efficient in strengthen wood while cotton fibers saturated with Paraloid B-72 followed by a mixture of Microballoon, ParaloidB-72 and earth pigments used as a final layer was suitable to fill gaps and voids.

Acknowledgments

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